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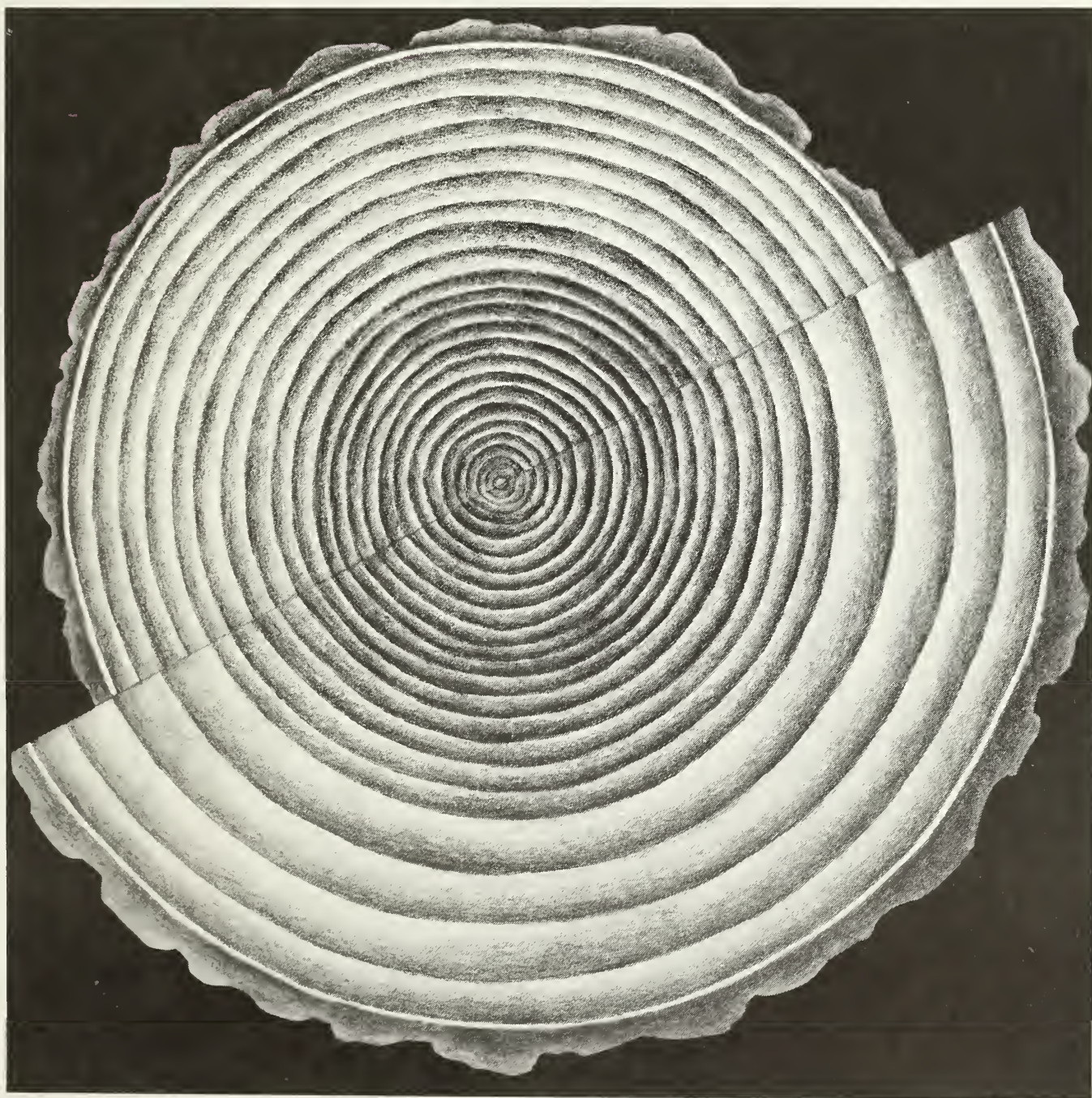
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Response of Sitka Spruce and Western Hemlock to Commercial Thinning

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Abstract

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Light commercial thinning in 100-year-old, well-stocked, mixed stands of western hemlock and Sitka spruce at Cascade Head Experimental Forest produced no consistent growth and yield responses related to thinning intensity. Mortality for all causes except windfall was generally less for thinned stands than for unthinned stands. Losses from windfall appear to be related more to location than to thinning.

Keywords: Commercial thinning, mixed stands, thinning effects, western hemlock, *Tsuga heterophylla*, Sitka spruce, *Picea sitchensis*, Oregon (Cascade Head Exp. For.), Cascade Head Exp. For.—Oregon.

Research Summary

Relatively light commercial thinning in a 100-year-old mixed stand of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on the Cascade Head Experimental Forest near Otis, Oregon, was prescribed to preserve wind firmness of the stands, recover or forestall mortality, and concentrate potential growth on selected trees. Thinning regimes proposed removal of 15 to 25 percent of the basal area. Thinning was done between 1947 and 1951. Measurements were made between 1947 and 1964 (table 10).

While light commercial thinning produced no consistent growth and yield responses related to thinning intensity, the unthinned natural stands averaged about 30 percent more gross growth and 10 percent more net growth than commercially thinned counterparts. The difference in gross and net growth is due primarily to the greater amount of unrecovered mortality in the unthinned areas. It appears that in these century-old forests, stands with a small (less than 20 percent) component of western hemlock may not respond as well to commercial thinning as stands with a larger (more than 35 percent) component of western hemlock. Gross growth seems to be greater in stands of higher density, both thinned and unthinned. In the least dense stand, however, with about 340 square feet of basal area per acre (78 m²/ha), gross growth was enhanced by commercial thinning.

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Introduction

The very dense coastal forests of the Sitka spruce (*Picea sitchensis* (Bong.) Carr.) zone (Franklin and Dyrness 1973) in Oregon and Washington are among the most productive coniferous forests in the world (Fujimori 1971) but are characteristically very susceptible to wind damage and mortality. To study the effect of commercial thinning on growth and yield in a 100-year-old stand of the Sitka spruce-western hemlock type, nine study tracts were established between 1947 and 1951 (fig. 1). Six of these tracts were thinned to various densities. Logging was done with horses, tractors, and a combination of the two. The three remaining unthinned tracts served as controls (tables 1 and 2).

The objective of the study was to evaluate growth and yield resulting from various thinning regimes and to determine whether thinning can reduce or forestall the amount of mortality and concentrate growth potential on trees in the residual stand.

The purpose of this report is to summarize and interpret data collected between 1947 and 1964 and to provide insight into the effects of thinning on growth and yield of the Sitka spruce-western hemlock type.



Figure 1.—A 1978 view of a 120-year-old Sitka spruce-western hemlock stand commercially thinned in 1947, Cascade Head Experimental Forest, Oregon.

Table 1—Description of study tracts and sample plots

Tract and treatment <u>1/</u>	Year established	Tract size		Number of plots	Plot size	Area sampled	Sampling intensity
		Acres	Hectares			--Acres--	Percent
18(UT)	1947	15	6	4	0.1	0.4	2.7
1B(T)	1947	25	10	6	.1	.6	2.4
1E(UT)	1947	61	24.7	16	.1	1.6	2.6
1E(T)	1947	100	40.5	28	.1	2.8	2.8
3C(UT)	1948	31	12.5	10	.2	2.0	6.5
3C(T)	1948	30	12.1	7	.2	1.4	1.8
8(T)	1950	7	2.8	8	.1	.8	11.4
9A(T)	1949	36	14.6	20	.1	2.0	2.3
10F(T)	1951	76	30.8	11	.2	2.2	2.9
Total unthinned		107	43.3	30	--	4.0	3.7
Total thinned		374	151.4	80	--	9.8	2.6
Total all plots		381	154.2	110	--	13.8	2.9

1/ UT = unthinned, T = thinned.

Table 2—Percent removal, proposed and accomplished, by stems per acre and cubic-foot volume to a 4-inch top and board-foot volume to a 6-inch top, by tract and thinning regimes (1947-51)

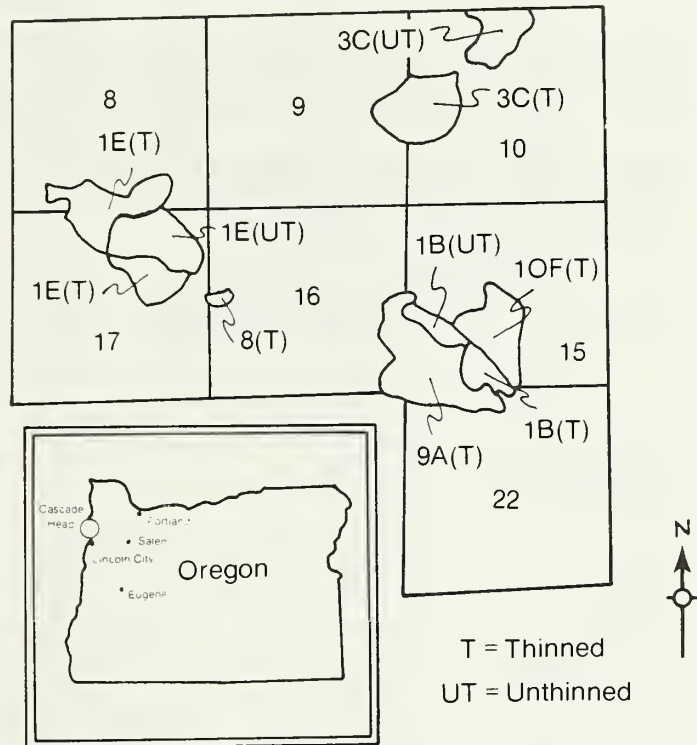
Tract and treatment <u>1/</u>	Proposed removal	Removed			
		Stems per acre	Basal area per acre	Volume	
				Cubic feet	Board feet
				Percent	
18(UT)	0	0	0	0	0
1B(T)	15	31.7	21.1	20.8	18.9
1E(UT)	0	0	0	0	0
1E(T)	25	30.7	22.1	24.7	23.5
3C(UT)	0	0	0	0	0
3C(T)	20	34.9	23.0	21.9	20.5
8(T)	25	17.3	15.9	15.9	14.8
9A(T)	15	23.6	13.3	12.1	10.9
10F(T)	20	33.5	21.2	20.8	18.6

1/ UT = unthinned; T = thinned.

Study Area

The study tracts are located in the Cascade Head Experimental Forest on the west slope of the Coast Ranges near Otis, Oregon (fig. 2).

The Cascade Head Experimental Forest was established by the USDA Forest Service in 1934 and has been maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with the Siuslaw National Forest.



Township 6 South, Range 10 West of the Willamette Meridian

Figure 2.—Approximate location and relative size of study tracts.

Climate

The climate is typical of the coastal fog belt and is characterized by mild temperatures, high humidity, frequent rain, and summer fog. Annual rainfall for the study area is approximately 90 inches (230 cm) and occurs primarily between October and April. The maritime influence of the Pacific Ocean results in a long growing season, with favorable moisture conditions the year around and only slight seasonal and diurnal fluctuations in temperature from the 50 °F (10 °C) mean (Madison 1957).

Site Index

Site index of the study stands could not be determined directly from the existing data. Studies conducted in similar nearby stands (Smith and others 1984) reveal an average site index of about 140 for western hemlock (Barnes 1962). For the purposes of this study the area is assumed to be of uniform site quality.

The Stand

The well-stocked, even-aged stands of Sitka spruce and western hemlock on the Cascade Head Experimental Forest are thought to have originated about 1850 following a severe forest fire.

Species composition and size distribution within the stands are indicated in tables 3 through 7, which summarize several basic stand parameters and provide insights into the similarities and dissimilarities of study tracts.

Table 3—Stand composition (western hemlock, Sitka spruce and Douglas-fir) based on stems per acre, before and after thinning and in 1964

Tract, treatment and species ^{1/}	Before thinning	After thinning (1947-51)	In 1964
-----Percent-----			
1B(UT):			
Western hemlock	75.4	--	76.0
Sitka spruce	23.1	--	22.0
O Douglas-fir	1.5	--	2.0
1B(T):			
Western hemlock	86.5	83.1	84.1
Sitka spruce	13.5	16.9	15.9
O Douglas-fir	0	0	0
1E(UT):			
Western hemlock	35.0	--	35.1
Sitka spruce	53.0	--	53.0
O Douglas-fir	12.0	--	11.9
1E(T):			
Western hemlock	33.7	29.7	29.2
Sitka spruce	56.1	60.8	62.6
O Douglas-fir	10.2	9.5	8.2
3C(UT):			
Western hemlock	56.4	--	58.5
Sitka spruce	32.7	--	32.1
O Douglas-fir	10.9	--	9.4
3C(T):			
Western hemlock	60.6	63.5	60.9
Sitka spruce	38.1	36.5	39.1
O Douglas-fir	1.3	0	0
8(T):			
Western hemlock	47.4	43.6	44.8
Sitka spruce	43.6	45.5	44.8
O Douglas-fir	9.0	10.9	10.4
9A(T):			
Western hemlock	77.6	76.6	74.6
Sitka spruce	15.5	17.0	18.7
O Douglas-fir	6.9	6.4	6.7
10F(T):			
Western hemlock	80.0	79.8	79.6
Sitka spruce	18.0	18.0	18.1
O Douglas-fir	2.0	2.2	2.3

^{1/} UT = unthinned, T = thinned.

Table 4—Average number of stems 2 inches (5.1 cm) d.b.h. and larger per acre and per hectare before and after thinning and in 1964

Tract and treatment <u>1/</u>	Stems before thinning		Stems after thinning (1947-51)		Stems in 1964	
	Per acre	Per hectare	Per acre	Per hectare	Per acre	Per hectare
18(UT)	162.5	401.5	--	--	125.0	308.9
18(T)	173.3	428.2	118.3	292.3	105.0	259.5
1E(UT)	114.4	282.7	--	--	105.0	259.5
1E(T)	119.6	295.5	83.5	206.3	69.6	172.0
3C(UT)	116.8	288.6	--	--	101.8	251.5
3C(T)	114.3	282.4	73.2	180.9	62.1	153.4
8(T)	166.3	410.9	139.2	344.0	131.3	324.4
9A(T)	145.5	359.5	117.0	289.1	104.5	258.2
10F(T)	184.5	455.9	126.1	311.6	118.2	292.1

1/ UT = unthinned, T = thinned.

Table 5—Average quadratic mean diameter, by tract and species, before and after thinning and in 1964

Tract, treatment and species <u>1/</u>	Diameter before thinning		Diameter after thinning (1947-51)		Diameter in 1964	
	Inches	Centimeters	Inches	Centimeters	Inches	Centimeters
1B(UT):						
Western hemlock	18.6	47.2	--	--	20.4	51.8
Sitka spruce	26.4	67.1	--	--	30.9	78.5
Douglas-fir	29.1	73.9	--	--	31.2	79.2
1B(T):						
Western hemlock	18.8	47.8	20.0	50.8	22.1	56.1
Sitka spruce	24.8	63.0	25.8	65.5	29.4	74.7
Douglas-fir	--	--	--	--	--	--
1E(UT):						
Western hemlock	15.8	40.1	--	--	17.8	45.2
Sitka spruce	28.5	72.4	--	--	31.6	80.3
Douglas-fir	23.0	58.4	--	--	24.8	63.0
1E(T):						
Western hemlock	16.2	41.1	16.0	40.6	18.1	46.0
Sitka spruce	23.9	60.7	24.9	63.2	27.7	70.4
Douglas-fir	24.4	62.0	24.8	63.0	28.4	72.1
3C(UT):						
Western hemlock	18.3	46.5	--	--	20.1	51.1
Sitka spruce	28.4	72.1	--	--	31.9	81.0
Douglas-fir	24.4	62.0	--	--	26.4	67.1
3C(T):						
Western hemlock	19.1	48.5	21.2	53.8	24.9	63.2
Sitka spruce	27.8	70.6	31.6	80.3	35.0	88.9
Douglas-fir	50.9	29.3	--	--	--	--
8(T):						
Western hemlock	19.3	49.0	18.7	47.5	21.0	53.3
Sitka spruce	25.4	64.5	26.2	66.5	27.7	70.4
Douglas-fir	21.5	54.6	21.5	54.6	22.8	57.9
9A(T):						
Western hemlock	19.4	49.3	20.7	52.6	21.7	55.1
Sitka spruce	28.9	73.4	29.7	75.4	32.7	83.1
Douglas-fir	22.5	57.2	22.9	58.2	25.9	65.8
10F(T):						
Western hemlock	17.9	45.5	19.3	49.0	20.9	53.1
Sitka Spruce	24.2	61.5	26.4	67.1	29.0	73.7
Douglas-fir	22.5	57.2	24.1	61.2	25.4	64.5

1/ UT= unthinned, T = thinned.

Table 6—Average basal area per acre and per hectare, by tract, before and after thinning and in 1964, and amount and percent removed

Tract and treatment <u>1/</u>	Basal area before thinning		Basal area after thinning (1947-51)		Basal area in 1964		Basal area removed		Percent of initial basal area removed
	ft ² /acre	m ² /ha	ft ² /acre	m ² /ha	ft ² /acre	m ² /ha	ft ² /acre	m ² /ha	
18(UT)	384.7	88.3	--	--	372.7	85.6	--	--	--
18(T)	365.5	83.9	288.1	66.1	314.1	72.1	77.4	17.8	21.1
1E(UT)	363.7	83.5	--	--	408.6	93.8	--	--	--
1E(T)	307.2	70.5	233.2	53.5	245.1	56.3	74.0	17.0	24.1
3C(UT)	329.6	75.7	--	--	350.0	80.3	--	--	--
3C(T)	342.0	78.5	254.3	58.4	290.3	66.6	77.7	17.8	22.7
8(T)	452.0	103.8	380.5	87.3	425.9	97.8	71.8	16.5	15.9
9A(T)	359.0	82.4	315.6	72.5	339.8	78.0	43.4	10.0	12.1
10F(T)	373.4	85.7	294.3	67.6	331.3	76.1	79.1	18.2	21.2

1/ UT = unthinned, T = thinned.

Table 7—Standing volume, by tract, before and after thinning and in 1964, in cubic feet to a 4-inch top and Scribner rule to a 6-inch top

Tract and treatment <u>1/</u>	Volume before thinning		Volume after thinning (1947-51)		Volume in 1964	
	ft ³ /acre	MBF/acre	ft ³ /acre	MBF/acre	ft ³ /acre	MBF/acre
18(UT)	20,020	121.6	--	--	22,399	137.3
18(T)	19,996	117.3	15,830	95.1	18,619	114.6
1E(UT)	18,841	119.2	--	--	23,147	150.3
1E(T)	15,577	93.7	11,731	71.7	13,606	84.6
3C(UT)	16,024	102.5	--	--	18,130	118.2
3C(T)	18,562	114.7	14,493	91.2	16,635	106.6
8(T)	22,865	142.1	19,240	121.0	22,594	143.7
9A(T)	20,389	123.1	17,921	109.7	20,397	126.6
10F(T)	21,916	125.5	17,356	102.2	19,956	120.9

1/ UT = unthinned, T = thinned.

Treatments

Between 1947 and 1951, 110 permanent sample plots were established in nine study tracts—three control and six to be treated by thinning.

The original tracts consisted of three pairs, one unthinned control and one treatment, without replication (1B unthinned and 1B thinned, 1E unthinned and 1E thinned, 3C unthinned and 3C thinned). Tracts 8, 9A and 10F were added to the study (see table 1). These three treatment tracts are not paired with control tracts, but, as figure 3 indicates, they are adjacent to or close to the other control tracts.

On the six treatment tracts almost 400 acres (160 hectares) were commercially thinned under regimes that proposed removing 15 to 25 percent of the total basal area (tables 8-12).

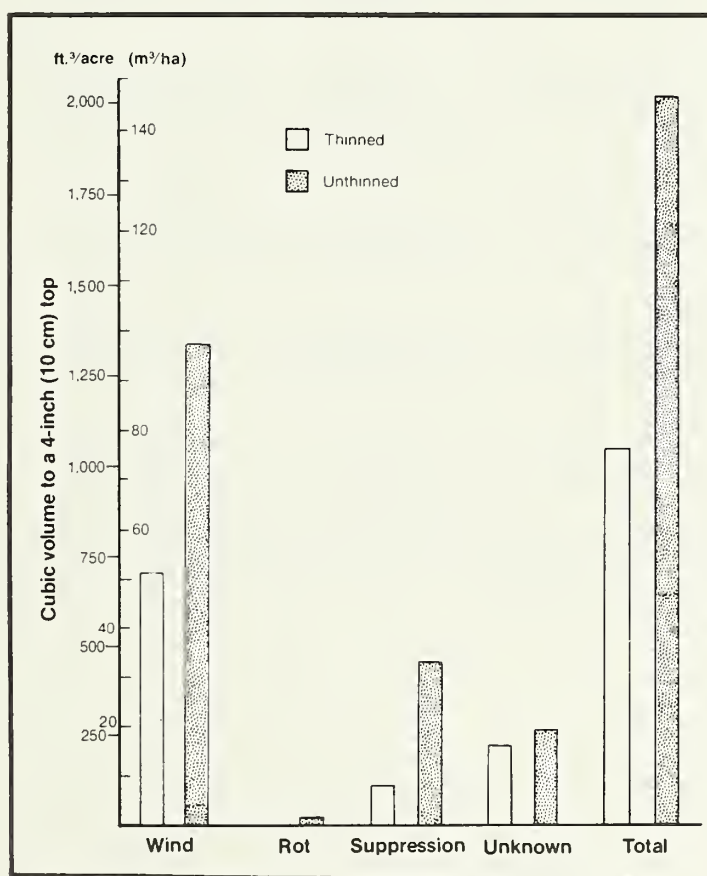


Figure 3.—Comparison of gross growth to initial basal area, by tract and treatment.

Table 8—Average trees per acre, basal area, and diameter of initial stand, and amount and percent removed from thinned tracts, by species, in English units

Tract and species	Initial stand			Amount removed			Percent removed		
	Trees/acre	Basal area	Diameter b.h.	Trees/acre	Basal area	Diameter b.h.	Trees/acre	Basal area	d/D ^{1/}
	ft ² /acre	in		ft ² /acre	in		ft ² /acre		
18:									
Western hemlock	150.0	287.6	18.7	51.7	71.6	15.9	34.5	24.9	.850
Sitka spruce	23.3	77.8	24.8	3.3	5.6	17.6	14.2	7.2	.712
O Douglas-fir	0	0	--	--	--	--	--	--	--
	173.3	365.4	19.7	55.0	77.2	16.0	31.7	21.1	.816
1E:									
Western hemlock	40.4	57.8	16.2	15.7	24.1	16.8	38.9	41.7	1.036
Sitka spruce	67.1	08.7	23.9	16.8	39.2	20.7	25.0	18.8	.866
Douglas-fir	12.5	40.6	24.4	4.3	4.6	23.0	34.4	11.3	.943
	120.0	307.1	21.7	36.9	67.9	19.4	30.8	22.1	.895
3C:									
Western hemlock	69.3	38.2	19.1	22.1	22.9	13.8	31.9	16.6	.721
Sitka spruce	43.6	83.8	27.8	16.4	36.0	20.1	37.6	19.6	.722
O Douglas-fir	1.4	19.8	50.9	1.4	19.8	50.9	100.0	100.0	1.000
	114.3	34.8	23.4	39.9	78.7	19.1	34.9	23.0	.315
8:									
Western hemlock	78.8	159.3	19.3	16.3	40.4	21.3	20.7	25.4	1.104
Sitka spruce	72.5	255.3	25.4	12.5	31.5	21.5	17.2	12.3	.846
Douglas-fir	15.0	37.7	21.5	0	0	--	0	0	--
	66.3	452.3	22.3	28.8	71.9	21.4	17.3	15.9	.960
9A:									
Western hemlock	114.0	233.0	19.4	30.5	38.7	15.3	26.8	16.6	.788
Sitka spruce	22.0	100.0	28.9	2.5	5.9	20.9	11.4	5.9	.723
O Douglas-fir	10.0	28.0	22.5	1.5	3.3	20.2	15.0	11.9	.896
	146.0	361.0	21.3	34.5	47.9	16.0	24.4	13.3	.751
10F:									
Western hemlock	147.7	257.3	17.9	50.9	60.4	14.8	34.5	23.5	.825
Sitka spruce	33.2	106.0	24.2	10.0	17.3	18.1	30.1	16.8	.747
O Douglas-fir	3.6	10.0	22.5	0.9	1.4	16.8	25.0	14.0	.746
	184.5	373.3	19.3	61.8	79.6	14.8	33.5	21.3	.770

^{1/} d = quadratic mean diameter of trees thinned, 0 = quadratic mean diameter of all trees prior to thinning.

Table 9—Average trees per acre, basal area, and diameter in initial stand, and amount and percent removed from thinned tracts, by species, in metric units

Tract and species	Initial stand			Amount removed			Percent removed		
	Trees/	Basal	Diameter	Trees/	Basal	Diameter	Trees/	Basal	d/D 1/
	hectare	area	b.h.	hectare	area	b.h.	hectare	area	
	m ² /ha	cm		m ² /ha	cm		m ² /ha		
1B:									
Western hemlock	371	26.7	47.5	128	6.7	40.7	34.5	24.9	.850
Sitka spruce	58	7.2	63.6	8	.5	44.7	14.2	7.2	.712
Douglas-fir	0	0	0	0	0	0	--	--	--
	429	33.9	50.0	136	7.2	40.6	31.7	21.1	.816
1E:									
Western hemlock	100	5.4	41.1	39	2.2	42.7	38.9	41.7	1.036
Sitka spruce	166	19.4	60.7	42	3.6	52.6	25.0	18.8	.866
Douglas-fir	31	3.8	62.0	11	.4	58.4	34.4	11.3	.943
	297	28.6	55.1	92	6.2	49.3	30.8	22.1	.895
3C:									
Western hemlock	171	12.8	48.5	55	2.1	35.1	31.9	16.6	.721
Sitka spruce	108	17.1	70.6	41	3.3	51.1	37.6	19.6	.722
Douglas-fir	3	1.8	29.3	3	1.8	129.3	00.0	100.0	1.000
	282	31.7	59.4	99	7.2	48.5	34.9	23.0	.315
18:									
Western hemlock	195	14.8	49.0	40	3.8	54.1	20.7	25.4	1.104
Sitka spruce	179	23.7	64.5	31	2.9	54.6	17.2	12.3	.846
Douglas-fir	37	3.5	54.6	0	0	0	0	0	
	411	42.0	59.4	71	6.7	54.4	17.3	15.9	.960
1E:									
Western hemlock	282	21.6	49.3	75	3.6	38.9	26.8	16.6	.788
Sitka spruce	54	9.3	73.4	6	.5	53.1	11.4	5.9	.723
Douglas-fir	25	2.6	57.2	4	.3	51.3	15.0	11.9	.896
	361	33.5	56.6	85	4.4	40.6	23.6	13.3	.751
3C:									
Western hemlock	365	23.9	45.5	126	5.6	37.6	34.5	23.5	.825
Sitka spruce	82	9.8	61.5	25	1.6	46.0	30.1	16.8	.747
Douglas-fir	9	.9	57.2	2	0.1	42.7	25.0	14.0	.746
	456	34.6	54.1	153	7.3	37.6	33.5	21.2	.770

1/ d = quadratic mean diameter of trees thinned, D = quadratic mean diameter of all trees prior to thinning.

Table 10—Schedule of measurements (M) and thinning (T)

Tract and treatment 1/	Proposed removal	1947	1948	1949	1950	1951	1952	1954	1956	1964
<u>Percent</u>										
18(UT)	0	M						M		M
1B(T)	15	M	T					M		M
1E(UT)	0	M							M	M
1E(T)	25	M	T	T 2/					TM 3/	M
3C(UT)	0		M						M	M
3C(T)	20		MT	T 2/					TM	M
8(T)	25				MT					M
9A(T)	15			MT	T	T 2/				M
10F(T)	20					M	T			M

1/ UT = unthinned, T = thinned.

2/ Records indicate that thinning operations occurred in more than one growing season but there is no indication that they were intended to be more than a single treatment.

3/ Intermediate cuttings to recover mortality occurred prior to measurement.

Table 11—Cubic volume removed from thinned tracts, by species, to a 4-inch (10.2 cm) top

Tract	Western hemlock		Sitka spruce		Douglas-fir		All species	
	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha
1B	3,866.2	270.5	299.4	20.9	--	--	4,165.6	291.5
1E	1,217.1	85.2	2,013.4	140.9	615.0	43.0	3,845.5	269.1
3C	1,137.5	79.6	2,003.1	140.2	928.0	64.9	4,068.6	284.7
8	1,955.6	136.8	1,669.4	116.8	--	--	3,625.0	253.6
9A	2,064.9	144.5	301.4	21.1	101.4	7.1	2,467.7	172.7
10F	3,450.6	241.4	1,039.4	72.7	70.9	5.0	4,559.9	319.1

Table 12—Cubic volume per acre and per hectare, by tract, before and after thinning, and amount removed by thinning and mortality, to a 4-inch (10.2-cm) top

Tract 1/	Before thinning		Removed by thinning (1947-51)		After thinning		Lost to mortality		Volume in 1964	
	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha
18(UT)	20,020	1,401	--	--	--	--	4,157	291	22,399	1,567
1B(T)	19,996	1,399	4,166	292	15,830	1,108	1,242	87	18,619	1,303
1E(UT)	18,481	1,293	--	--	--	--	815	57	23,147	1,620
1E(T)	15,577	1,090	3,845	269	11,732	821	1,725	121	13,606	952
3C(UT)	16,024	1,121	--	--	--	--	1,366	96	18,130	1,269
3C(T)	18,562	1,299	4,069	285	14,494	1,014	1,277	89	16,635	1,164
8(T)	22,865	1,600	3,625	254	19,240	1,346	689	48	22,954	1,581
9A(T)	20,389	1,427	2,468	173	17,921	1,254	1,277	89	20,397	1,427
10F(T)	21,916	1,533	4,560	319	17,356	1,214	414	29	19,956	1,396

1/ UT = unthinned, T = thinned.

Thinning

Examination of stand table data suggests that the thinnings were a combination of low- and crown-methods, although some of the entries were termed sanitation and salvage cuttings. These thinnings were relatively light to preserve the wind firmness of the characteristically shallow-rooted trees. The decision to thin lightly may also have been based on the presumption that heavier thinning would have reduced growth on residual trees to the point where it could not compensate for potential lost growth when trees were cut.

The main objectives of thinning were to recover or forestall mortality and concentrate potential growth on the better trees.

Measurements

From the existing field records,^{1/} it appears that the initial measurements were made when the study tracts were established. At that time, diameter at breast height was measured on all plot trees. Some trees were measured for total height, but none were bored to determine age. Subsequent periodic measurements and mortality observations were taken for growth comparison (tables 10, 12 and 13).

Table 13—Summary of growing seasons between measurements by tract and treatment

Tract and treatment	First period	Second period	Total observation period
<u>Growing seasons</u>			
1B, unthinned	7	11	18
1B, thinned	7	11	18
1E, unthinned	9	9	18
1E, thinned	9	9	18
3C, unthinned	7	9	16
3C, thinned	7	9	16
8, thinned	15	-	15
9A, thinned	16	-	16
10F, thinned	13	-	13

Methods

Volume Computation

In this study volume estimates utilize tariff-volume equations computed with British Columbia volume-equation coefficients for immature coastal western hemlock, Sitka spruce, and Douglas-fir (Brackett 1973).

Only a portion of the sample trees was measured for total height at any one measurement. The same trees were not always remeasured. On some trees height measurements were inconsistent, indicating negative or highly fluctuating height growth.

^{1/} Data on file at Forestry Sciences Laboratory, Corvallis, Oregon, under study W-26, dated 1947, by Robert H. Ruth.

Therefore, we computed tariff access numbers only from trees measured more than once and showing increased height growth. This procedure was necessary to eliminate the inconsistencies in stand growth found in the preliminary analyses. These data are summarized in table 14. Generally, the annual tariff increments appear to correspond well with the findings of Reukema and Pienaar (1973) and Graham (1978). In most instances, these modest tariff increments should result in conservative estimates of volume growth.

Table 14—Average tariff numbers by tract, species, and measurement period

Tract, treatment, and species ^{1/}	Average tariff number ^{2/}			Average annual tariff increment
	First measurement	Second measurement	Third measurement	
1B(UT):				
Western hemlock	49.6	54.1	57.9	.46
Sitka spruce	49.6	51.9	55.7	.34
Douglas-fir	40.1	41.8	43.0	.16
1B(T):				
Western hemlock	52.4	53.6	55.8	.19
Sitka spruce	51.0	51.9	55.5	.25
Douglas-fir	42.2	43.8	45.2	.17
1E(UT):				
Western hemlock	43.0	47.6	49.7	.37
Sitka spruce	49.7	52.7	54.9	.29
Douglas-fir	40.1	42.5	43.0	.16
1E(T):				
Western hemlock	44.7	47.1	49.3	.26
Sitka spruce	47.3	49.7	51.0	.21
Douglas-fir	42.2	43.8	45.2	.17
3C(UT):				
Western hemlock	44.9	46.6	47.8	.18
Sitka spruce	47.8	49.1	50.1	.14
Douglas-fir	40.1	42.5	43.0	.18
3C(T):				
Western hemlock	46.3	37.9	49.2	.18
Sitka spruce	52.0	53.2	53.3	.08
Douglas-fir	42.2	43.8	45.2	.17
8(T):				
Western hemlock	45.9	48.5	--	.17
Sitka spruce	50.2	51.9	--	.11
Douglas-fir	37.9	40.6	--	.18
9A(T):				
Western hemlock	53.8	56.0	--	.14
Sitka spruce	55.6	58.4	--	.18
Douglas-fir	46.3	49.2	--	.18
10F(T):				
Western hemlock	56.3	56.9	--	.05
Sitka spruce	55.9	57.0	--	.08
Douglas-fir	49.1	50.4	--	.10

^{1/} UT = unthinned, T = thinned.

^{2/} Tariff number as defined by the Washington State Department of Natural Resources Tariff Tables (Bracket 1973)

Volume Growth

A summary of average annual volume growth is presented in table 15. Comparing averages for the control and treatment areas reveals that the natural stands in this study average about 30 percent more gross growth and about 10 percent more net growth than their commercially thinned counterparts. This difference in gross and net growth is due primarily to the greater amount of unrecovered mortality in the control areas.

Tract 3C(T) and its control, Tract 3C(UT), are the only paired tracts in which gross and net volume growth are essentially equal (table 15). These tracts are also the only two in which western hemlock was not reduced in both basal area and number of stems per acre.

Table 15—Periodic annual increment, in cubic volume of trees to a 4-inch (10.2-cm) top and Scribner board-foot volume to a 6-inch top

Tract and treatment ^{1/}	Cubic volume				Scribner rule	
	Gross		Net		Gross	Net
	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	board ft/acre	
1B (UT)	363	25.4	132	9.2	2,225	809
1B (T)	224	15.7	155	10.8	1,379	954
1E (UT)	304	21.3	259	18.1	1,974	1,681
1E (T)	200	14.0	104	7.3	1,288	670
3C (UT)	217	15.2	132	9.2	1,415	861
3C (T)	211	14.8	134	9.4	1,399	887
8 (T)	270	18.9	224	15.7	1,717	1,424
9A (T)	235	16.4	155	10.8	1,459	962
10F (T)	232	16.2	200	14.0	1,405	1,211
Averages						
Unthinned	295	20.6	174	12.2	1,871	1,117
Thinned	229	16.0	162	11.3	1,441	1,018

^{1/} UT = unthinned, T = thinned.

The paired control and treatment areas, tracts IE(UT) and IE(T) had the highest and lowest periodic annual increment—net cubic volume (table 15). These two stands also have the smallest western hemlock component (tables 3 and 16) of all stands in the study. These data seem to suggest that in century-old stands of this cover type, those with a smaller component of western hemlock may not respond as well to commercial thinning. Perhaps this response is merely a reflection of the silvics of this species.

Generally, gross growth is greater in higher density stands, both thinned and unthinned (fig. 3).

Computation of mean annual increment (MAI) for these stands was not possible with the existing data base.

Table 16—Percentage of western hemlock in all tracts, by basal area at initial measurement (1947-51) and final measurement in 1964

Tract and treatment <u>1/</u>	Initial measurement	Final measurement
-----Percent-----		
1B(UT)	59.8	58.0
1B(T)	78.7	75.0
1E(UT)	15.0	15.6
1E(T)	18.8	15.1
3C(UT)	36.4	37.6
3C(T)	40.4	44.1
8(T)	35.2	33.1
9A(T)	63.8	59.0
10F(T)	68.9	67.6

1/ UT = unthinned, T = thinned.

Mortality

Losses in growth and growing stock to natural or human-caused mortality (table 17) are difficult to assess. Each stand presents a unique situation of inter-related mortality factors (wind, decay, age, and logging damage) whose complexity is far beyond the analysis presented here. Some observations can be made by comparing thinned and control tracts, but exceptions are found within individual treatment areas.

Table 17—Volume of mortality in trees to a 4-inch (10.2-cm) top, to 1964, by cause, excluding damage caused by thinning

Tract and treatment 1/	Thinned (1947-51)		Wind		Rot		Suppression		Unknown		Total mortality	
	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha	ft ³ /acre	m ³ /ha
18(UT)	0	0	2,900.0	202.9	0	0	822.7	57.6	433.4	30.3	4,156.1	290.8
18(T)	4,165.6	291.5	468.9	32.8	0	0	106.4	7.4	666.8	46.7	1,242.1	86.9
1E(UT)	0	0	187.0	13.1	0	0	304.8	21.3	323.6	22.6	805.4	56.4
1E(T)	3,845.5	269.1	1,370.6	95.9	0	0	161.8	11.3	191.1	13.4	1,724.5	120.7
3C(UT)	0	0	929.1	65.0	45.4	3.2	291.1	20.4	87.5	6.1	1,353.1	94.0
3C(T)	4,068.6	284.7	887.4	62.1	0	0	0.8	0.1	339.1	23.7	1,227.3	85.9
8(T)	3,625.0	253.6	528.5	37.0	0	0	101.5	7.1	59.2	4.1	689.2	48.2
9A(T)	2,467.7	172.7	822.8	57.6	0	0	326.8	22.9	128.0	9.0	1,277.4	89.4
10F(T)	4,559.9	319.1	359.5	25.2	0	0	47.1	3.3	7.3	0.5	413.9	29.0
Averages												
Unthinned	0	0	1,338.7	93.7	5.1	1.1	472.8	33.1	261.5	18.3	2,078.1	145.4
Thinned	3,788.7	265.1	739.3	51.7	0	0	124.1	8.7	231.9	16.2	1,095.3	76.6

1/ UT = unthinned, T = thinned.

Results and Discussion

Light commercial thinning in century-old stands of Sitka spruce and western hemlock produced no consistent growth and yield responses related to thinning intensity. It appears that stands with a hemlock component larger than 35 percent respond best to commercial thinning.

The effect of logging operations on mortality is difficult to discern. Although mortality due to logging damage was listed as a category for the study, no mortality was directly attributed to this factor. In the thinned stands, some of the windthrow losses may have been related to logging activity.

A closer examination of the windthrow losses (table 17) reveals that the control areas have by far the greatest range and variation with respect to this cause of mortality. The windthrow losses of tract 10F may tend to distort the results. It may be that this tract, which suffered the greatest losses to the windstorms of December 4, 1951, Columbus Day 1962, and others, may have been particularly susceptible, because of some combination of predisposing factors. All windthrow losses in tract 1B(UT) occurred on half the plots. The adjacent, and presumably quite similar treatment area, tract 1B(T), incurred wind losses less than one-sixth that of its control, tract 1B(UT).

Generally, the unthinned control tracts had greater losses from wind and suppression. Data on average mortality, excluding thinning removals, represented in figure 4 and table 17, make it quite obvious that mortality in all categories was greater in the unthinned control tracts.

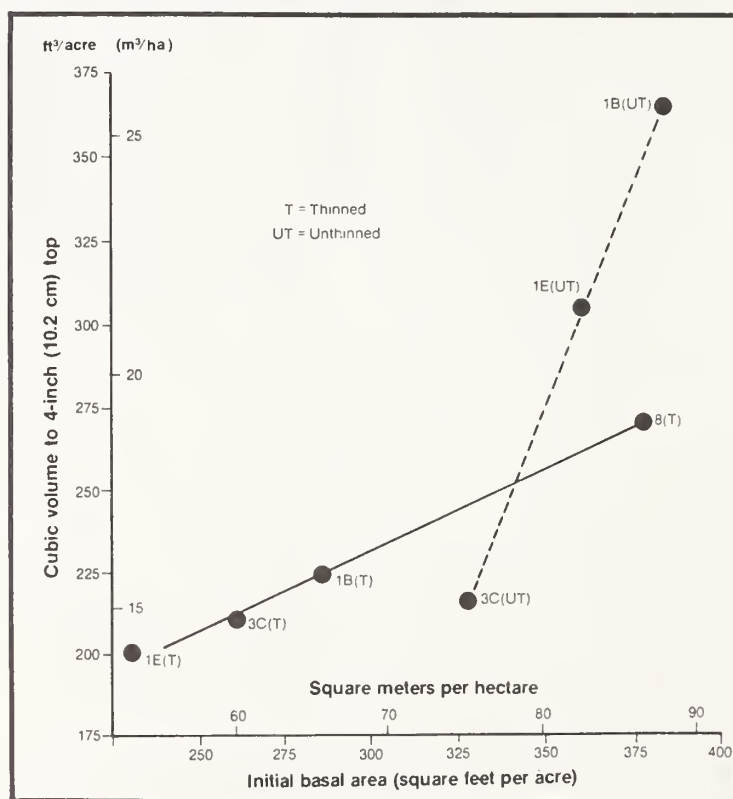


Figure 4.—Average cumulative mortality in all tracts from wind, rot, suppression, and unknown causes.

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Light commercial thinning in 100-year-old, well-stocked, mixed stands of western hemlock and Sitka spruce at Cascade Head Experimental Forest produced no consistent growth and yield responses related to thinning intensity. Mortality for all causes except windfall was generally less for thinned stands than for unthinned stands. Losses from windfall appear to be related more to location than to thinning.

Keywords: Commercial thinning, mixed stands, thinning effects, western hemlock, *Tsuga heterophylla*, Sitka spruce, *Picea sitchensis*, Oregon (Cascade Head Exp. For.), Cascade Head Exp. For.—Oregon.

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